NAG5-844

To what Extent is Mass Loading Responsible for the Venus Bowshock Precursor?

Ernest G. Fontheim
Space Physics Research Laboratory
Department of Atmospheric, Oceanic, and Space Sciences
The University of Michigan
Ann Arbor, Michigan 48109

Larry H. Brace
Laboratory for Atmospheres
NASA Goddard Space Flight Center
Greenbelt, Md. 20771

ABSTRACT

Significant ion and electron flux enhancements immediately upstream of the Venus bowshock have been observed by the Electron Temperature Probe on the Pioneer Venus Orbiter. It is shown that mass loading of the solar wind by oxygen ions accounts for only about 10% of the observed effect.

INTRODUCTION

Recent observations by the Electron Temperature Probe on the Pioneer Venus Orbiter indicate enhanced electron and ion currents immediately upstream of the Venus bowshock (Brace et al., 1985; Brace, 1987). Mass loading of the upstream particle flux will be examined in this paper as a potential mechanism which could give rise to such a phenomenon.

Venus is known to have a hot oxygen corona (Nagy et al., 1981: Paxton, 1983) resulting in an extended atmosphere. Oxygen is the dominant neutral gas species on the dayside out to distances of about 3000 km during solar maximum conditions (Kliore et al., 1986). The bowshock is located at an altitude of only about 2300 km at the subsolar point during solar maximum (Luhmann, 1986) which is inside the region of this hot oxygen corona. The oxygen atoms are ionized by either photoionization or charge exchange with solar wind protons. The O^+ ions are then picked up by the solar wind, thus mass loading the flow. As a result of this energy

(NASA-TM-89307) TO WHAT EXTENT IS MASS LOADING RESPONSIBLE FOR THE VENUS BOWSHOCK PRECURSOR? (NASA) 9 p CSCL 03B

N88-20239

Unclas
G3/91 0133332

transfer from the solar wind protons to the O^+ ions, the bulk flow velocity decreases. This decrease in the solar wind flow velocity as well as the addition of O^+ result in an increase in the ion (and electron) number density of the mass loaded solar wind.

DISCUSSION OF THEORY AND UNDERLYING ASSUMPTIONS

The calculations presented here make use of earlier work on the solar wind interaction with comets (Wallis and Ong, 1975; Galeyev et al., 1985) with appropriate modifications for the situation at Venus. The purpose of this paper is to establish qualitatively the feasibility of mass loading as a cause of the precursor; therefore the calculations are simplified as much as possible. The calculations described in this paper are based on the following assumptions: 1) One-dimensional flow, 2) magnetic field perpendicular to the solar wind velocity vector, 3) no pitch angle or energy diffusion of the implanted O^+ ions, and 4) conservation of the first invariant of the implanted ions.

The photoionization rate of oxygen atoms is given by the expression

$$R_{ph} = n_o \int_{E_i/h}^{\infty} \sigma_p(\nu)\Phi(\nu)d\nu \qquad (1)$$

where

R_{ph} = number of O^+ ions produced by photoionization per unit volume per unit time,
n_o = hot atomic oxygen density,
E_i = oxygen ionization potential,
h = Planck's constant
$\sigma_p(\nu)$ = photoionization cross section of oxygen for photons of frequency ν,
$\Phi(\nu)d\nu$ = photon flux in the frequency range $d\nu$ about ν.

Let

$$\Sigma \equiv \int_{E_i/h}^{\infty} \sigma_p(\nu)\Phi(\nu)d\nu, \qquad (2)$$

then $$R_{ph} = n_o \Sigma. \quad (3)$$

The production rate of O^+ ions by charge exchange is given by

$$R_{ce} = n_o \sigma_{ce}(E_p) \Phi_{SW}, \quad (4)$$

where

R_{ce} = number of O^+ ions produced by charge exchange between O and H^+ per unit volume per unit time,

$\sigma_{ce}(E_p)$ = charge exchange cross section of O with solar wind H^+ of energy E_p (2×10^{-9} erg for a typical solar wind velocity of 450 km/s at solar maximum),

Φ_{SW} = H^+ flux (solar wind) = $n_\infty u_\infty$,

and n_∞, u_∞ are the unperturbed solar wind density and velocity respectively.

Hence, the total O^+ production rate is given by

$$R_T = R_{ph} + R_{ce} = n_o[\Sigma + \sigma_{ce}(E_p) \Phi_{SW}]. \quad (5)$$

R_T is considered to be only a function of the altitude. The two cross sections and fluxes are considered to be constant in space and time. The altitude dependence of R_T is a result of the altitude dependence of n_o. The calculations presented here are based on separate continuity equations, one for the implanted O^+ ions and one for the contaminated solar wind, and a momentum equation for the contaminated solar wind. Under the given assumptions the upstream solar wind is described by the following equations

$$(d/dx)[\rho_i u f(u,\mu)] = m_i n_o(\Sigma + \sigma_{ce}\Phi_{SW})\delta(\mu - m_i u^2/2B) \quad (6)$$

$$(d/dx)(\rho u) = m_i n_o(\Sigma + \sigma_{ce}\Phi_{SW}) \quad (7)$$

$$(d/dx)(\rho u^2 + p_\perp + B^2/8\pi) = 0. \quad (8)$$

Here the x-axis is along the Venus-sun line with origin at the sun, ρ_i is the mass density of the implanted O^+ ions, u is the solar wind velocity, $f(u, \mu)$ is the velocity distribution function of implanted O^+ ions, $\mu = m_i v_\perp^2/2B$ is the magnetic moment of the implanted O^+ ions, B is the magnitude of the interplanetary magnetic field, $\delta(x)$ is the Dirac delta function, ρ is the mass density of the mass loaded solar wind, and m_i is the mass of the O^+ ion. The solution to these equations is (Biermann et al., 1967; Galeyev et al., 1985)

$$\hat{\rho}\hat{u} = 1 + (m_i/\rho_\infty u_\infty)(\Sigma + \sigma_{ce}\Phi_{SW})\int_{x^*}^{x_{bo}} n_O(x')dx' \qquad (9)$$

$$\hat{\rho} = 2\hat{\rho}\hat{u}[1 - (1 - 3\hat{\rho}\hat{u}/4)^{1/2} \qquad (10)$$

$$\hat{u} = (2/3\hat{\rho}\hat{u})[1 + (1 - 3\hat{\rho}\hat{u}/4)^{1/2}] \qquad (11)$$

$$\rho_i u f(u,\mu) = \frac{4(\hat{\mu}^{\frac{1}{3}} - 0.5)}{9\hat{\mu}^{\frac{5}{3}}\mu_{bo}} \rho_\infty u_\infty \Theta(\mu_\infty - \mu)\Theta(\mu - \mu_\infty \hat{u}^3) \qquad (12)$$

where $\hat{\rho}$, $\hat{u}$, and $\hat{\mu}$ are the solar wind parameters normalized to their unperturbed values ρ_∞, u_∞, μ_∞ and where $\mu_\infty = m_i u_\infty^2/2B_\infty$ and $\Theta(x) = 1$ for $x \geq 0$ and $\Theta(x) = 0$ for $x < 0$. Hence, under the assumption of the conservation of the first invariant, the magnetic moment of the implanted ions is restricted to the range

$$\mu_\infty \hat{u}^3 < \mu < \mu_\infty.$$

The total mass density of the implanted ions is therefore

$$\int_{\hat{\mu}^3}^{\mu_{bo}} \rho_i f(u,\mu)d\mu = (1/3)\rho_\infty \hat{u}^{-1}(-3 + 4\hat{u}^{-1} - \hat{u}^{-2}). \qquad (13)$$

RESULTS

The hot atomic oxygen density profile for solar maximum conditions, shown in Figure 1, was obtained from ultraviolet spectrometer measurements made onboard the Pioneer Venus Orbiter (Paxton, 1983). This results in a column density, defined by the integral in equation (9), of 2.4×10^{11} cm^{-2}. The atomic oxygen photoionization rate Σ of $4.5 \times 10^{-7} s^{-1}$ at 1 AU for solar maximum conditions was obtained from Table 7.19 of Banks and Kockarts (1973), which gives a value of 8.6×10^{-7} s^{-1} at the Venus orbit of 0.723 AU. The charge exchange cross section for neutral oxygen atoms with solar wind protons has been taken to be 1.5×10^{-15} cm^2 (equation 9.88 of Banks and Kockarts, 1973). The unperturbed solar wind parameters at 1 AU are taken to be $n_\infty = 6$ cm^{-3}, $u_\infty = 4.5 \times 10^7$ cm/s which translates into a flux of 5.2×10^8 $cm^{-2} s^{-1}$ at 0.723 AU.

Upon substituting these values into equation (9) one obtains

$$\hat{\rho}\,\hat{u} = 1 + 1.4 \times 10^{-2}$$

or

$$\rho u = (1 + 1.4 \times 10^{-2})\, \rho_\infty u_\infty,$$

which represents a 1.4% increase in the mass flow. If this solution is substituted into equation (10), one obtains

$$\hat{\rho} = 1 + 3.5 \times 10^{-2}$$

which represents a 3.5% increase in the mass density. This increase contains the combined effects of the addition of implanted ions and the increase in number density of the solar wind protons caused by the decrease in the flow velocity. The latter, of course, is a consequence of mass loading and can be obtained from equation (11),

$$\hat{u} = 1 - 2.1 \times 10^{-2}.$$

Hence, the mass loading results in a slowdown of 2.1% in the solar wind speed in front of the Venus bowshock. We are now in a position to calculate the mass density of the implanted O^+ ions and

the increase in the number density of H^+ ions. Using the parameters listed above, the mass density of implanted O^+ ions is obtained from equation (13)

$$\rho_i \int_{\sqrt{2}^3 \mu_{s0}}^{\mu_{s0}} f(u,\mu)d\mu = 1.4 \times 10^{-2}\rho_\infty.$$

Thus a 1.4% mass density increase is due to the addition of O^+ to the flow. The remaining 2.1% increase (to give a total mass density increase of 3.5%) is due to the density increase in solar wind protons.

CONCLUSIONS

If the observed 30% electron flux enhancement in the precursor is assumed to be entirely due to a corresponding density enhancement in the upstream solar wind, it is of interest to calculate the required atomic oxygen column density which is necessary to obtain such a density change. This turns out to be a column density of 3.2×10^{12} cm^{-2} which is about one order of magnitude larger than the column density used in the above calculations. No atomic oxygen column density of that magnitude has been observed by Pioneer Venus (Paxton, personal communication). Therefore these calculations indicate that mass loading of the solar wind flow in front of the bowshock cannot be the sole mechanism responsible for the observed enhancements in the electron and ion fluxes. The observed increases in the Langmuir probe collection current must either be the result of some unexpected instrumental and/or spacecraft phenomenon or the result of some physical process in the preshocked solar wind flow that has not been considered to this date.

ACKNOWLEDGMENTS

This research was supported by NASA Grant NAG 5-844 to the University of Michigan. The authors are grateful to T.C. Cravens for helpful suggestions and to A.F. Nagy for his critical reading of the manuscript.

REFERENCES

Banks, P.M., and G. Kockarts, Aeronomy, Part A, Academic Press, New York and London, 1973

Biermann, L., B. Brosowski, and H.U. Schmidt, The interaction of the solar wind with a comet, Solar Phys. 1, 254, 1967

Brace, L.H., S.A. Curtis, C.T. Russell, and F.L. Scarf, A precursor to the Venus bowshock, Trans. Am. Geophys. U. (EOS), 66, 294, 1985

Brace, L.H., Additional Pioneer Venus observations of the precursor to the Venus bowshock, Trans. Am. Geophys. U. (EOS), 68, 342, 1987

Galeyev, A.A., T.E. Cravens, and T.I. Gombosi, Solar wind stagnation near comets, Astrophys. J., 289, 807, 1985

Kliore, A.J., V.I. Moroz, G.M. Keating, ed's., The Venus International Reference Atmosphere, Pergamon Press, Oxford, U.K., 1986 (Chapter IV.4)

Luhmann, J.G., The solar wind interaction with Venus, Space Sci. Rev., 44, 241, 1986

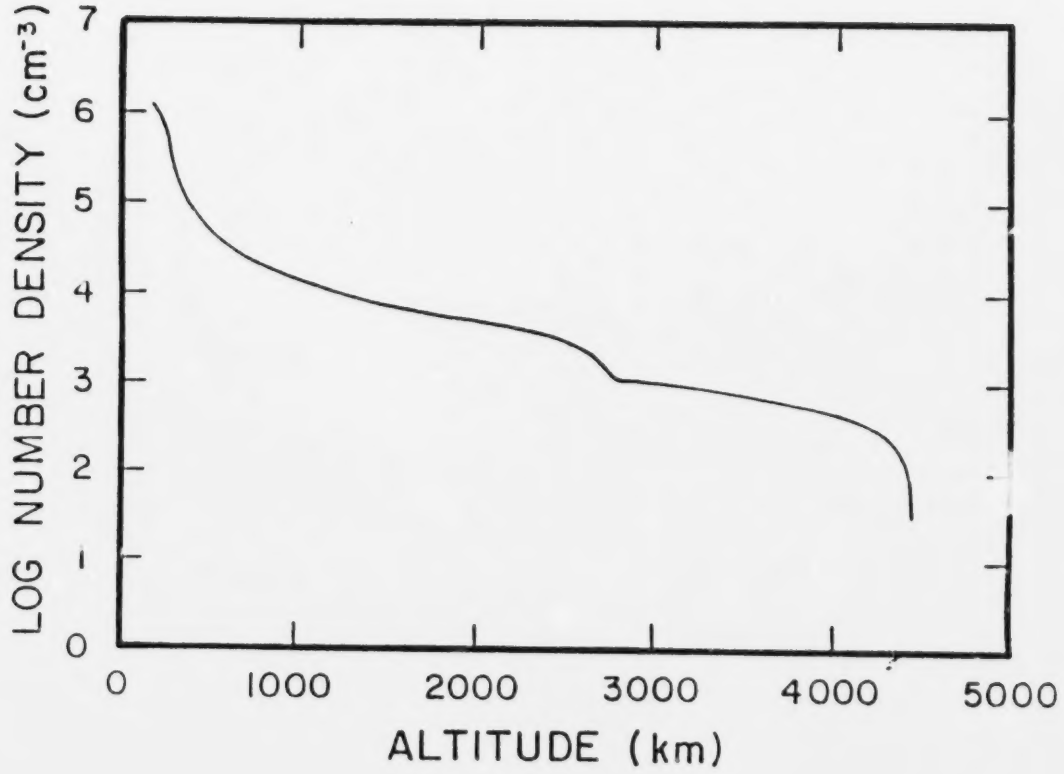
Nagy, A.F., T.E. Cravens, J.-H. Yee, and A.I.F. Stewart, Hot oxygen atoms in the upper atmosphere of Venus, Geophys. Res. Lett., 8, 629, 1981

Paxton,L.J., Atomic Carbon in the Venus Thermosphere: Observations and Theory, Thesis, Department of Astro-Geophysics, University of Colorado, 1983

Wallis, M.K., and R.S.B. Ong, Strongly-cooled ionizing plasma flows with application to Venus, Planet. Space Sci., 23, 713, 1975

FIGURE CAPTION

FIGURE 1: Hot atomic oxygen density distribution in the upper atmosphere of Venus (Figure B-8 of Paxton, 1983)


LOG NUMBER DENSITY (cm⁻³)
7
6
5
4
3
2
1
0
0
1000
2000
3000
4000
5000
ALTITUDE (km)